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The purpose of this research was to (1) develop new tests of spatial-visual ability that relate to later learning and performance, (2) relate the new measures to existing measures of cognitive ability, and (3) provide the new measures to the Navy for further investigation as personnel classification tools. The theoretical goal of this research was to improve our understanding of how spatial abilities relate to later learning and performance. We have completed seven experiments that examine the role of individual differences in cognitive ability and how they effect strategic processing of meaningful stimuli and inter-stimuli strategic transfer. Our findings suggest that spatial ability plays a central role in the ability to acquire and transfer optimal strategic processing skills. Individuals with medium ability (those most likely to enter the Navy) are most sensitive to the initial training context during the formation of their strategic processing skills.

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FINAL TECHNICAL REPORT

GRANT #: N00014-01-1-0093

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INSTITUTION: Mississippi State University

GRANT TITLE: New Measures of Complex Spatial Processing Abilities: Relating Spatial Abilities to Learning and Performance

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OBJECTIVE: The purpose of this research was to (1) develop new tests of spatial-visual ability that relate to later learning and performance, (2) relate the new measures to existing measures of cognitive ability, and (3) provide the new measures to the Navy for further investigation as personnel classification tools. The theoretical goal of this research was to improve our understanding of how spatial abilities relate to later learning and performance. This research also sought to expand the classification tools available to identify sailors with high spatial abilities. Improving identification will enhance the match between sailor skills and the cognitive demands of the occupations that require high spatial skills. This was a three-year project, but year three funding was not available. As a result the third objective of this research was not accomplished.

APPROACH: The goal of this project was to examine the cognitive abilities that support the acquisition, transfer, and modification of optimal strategic spatial processing skills. Optimal strategic processing can be partially characterized as the ability to learn processing strategies that (1) differentiate between relevant and irrelevant information and (2) are sufficiently detailed to accommodate the most difficult comparisons. In general, good performers are likely to know which task information is relevant and which is irrelevant and are therefore able to focus their processing on task-relevant information. In contrast, poor performers do not have the ability to distinguish between task-relevant and task-irrelevant information. One aspect of acquiring a spatial comparison skill, then, appears to be the ability to limit task processing to task-relevant information. This is referred to in the literature as information reduction strategies (e.g., Doane et al., 1999; Haider & Frensch, 1999). Information reduction strategies are acknowledged in many areas of psychology. The phenomenon has been discussed theoretically for the domains of visual perception (e.g., Gibson, 1963), sports and perceptual motor skills (e.g., Abernathy, 1993), educational psychology (e.g., Bransford, Sherwood, Vye, & Rieser, 1986), and expertise (e.g., Ericsson & Lehmann, 1996). Recent research published in the cognitive literature (e.g., Doane et al., 1996; 1999; Haider & Frensch, 1999) has made both theoretical and applied contributions to our understanding of human learning and performance. The Doane et al. studies are limited by the fact that they use normative methods to evaluate differences at the group level. Unfortunately, aggregation of performance observed from multiple individuals often results in a performance profile not representative of any one individual (Pellegrino et al., 1986; Wolfe et al., 1995). Thus, existing research does not examine how individual differences in cognitive abilities support the acquisition, transfer, and modification of strategic spatial processing skills. The proposed studies will relate individual differences in cognitive ability to strategic spatial processing skills.

ACCOMPLISHMENTS: We completed 7 experiments and ran 483 subjects to determine the role of individual differences in cognitive ability and how they impact the acquisition and transfer of strategic processing skills. The findings from three experiments are summarized below, and additional experiments are described in published manuscripts.

The first experiment examined whether strategic skill acquisition would influence discrimination on meaningful stimuli (airframe silhouettes). Previous research examined only abstract stimuli, such as random polygons, and it was not clear if strategic processing would impact performance for stimuli with which subjects were familiar. In the experiment, subjects trained in either difficult discriminations (discriminations between very similar airframes) or easy visual discriminations (discriminations between very dissimilar airframes) between airframe silhouettes in Session 1 and then transferred to making difficult discriminations in Session 2. In Session 3, subjects viewed stimuli at all discrimination difficulty levels

(difficult and easy). The accuracy and reaction times results showed subjects initially trained on easy discriminations were more accurate and faster at making discriminations than subjects trained on difficult discriminations in Session 1. However, upon transfer to a completely novel set of airframe silhouette stimuli in Session 2, subjects initially trained on difficult discriminations were more accurate and faster in their discriminations than those initially trained on easy discriminations, and this effect continued into session 3, where subjects from both training groups viewed stimuli at all levels of difficulty.

The results are consistent with the hypothesis that strategic skills acquired during initial training are derived from exposure to specific stimuli, but not tied to them per se. The transfer session results are consistent with the hypothesis that the difficult training group acquired a strategy during training that positively transferred to discriminating between novel difficult discriminations in Sessions 2 and 3. In contrast, the strategy acquired by the easy discrimination group was optimal for easy discriminations, but negatively transferred to novel difficult discriminations. In summary, the findings of strategic skill acquisition and transfer obtained using abstract and meaningless stimuli were obtained using meaningful stimuli.

Our second significant finding was that strategic skills acquired during initial training transfer between stimulus categories. We discovered this by using stimulus sets from two different categories, airframe silhouettes and random polygons. In this experiment, subjects were initially trained to make easy or difficult discriminations between either random polygons or airframe silhouettes in Session 1. At transfer (Session 2), they were asked to make difficult discriminations between the stimulus category not viewed during Session 1 (e.g., if they viewed polygons in Session 1, then they viewed airframe silhouettes in Session 2 and 3). As in the previously reported experiment, the difficult-first discrimination training group showed superior transfer to novel stimulus categories in Session 2, and this pattern of results persisted through extended practice trials in Session 3. In addition, the strategic skills initially acquired by the easy discrimination group showed the same negative impact at transfer to the novel category of stimuli. Because the two groups in this and the previous experiment had identical stimulus-specific experience with the transfer stimuli at the start of Session 2 (none), the results cannot be explained in terms of stimulus-specific skills. Rather, they are more consistent with the acquisition and transfer of strategic skills borne from processing specific stimuli, but not tied to them per se.

The third experiment summarized here examined the role of individual differences in cognitive abilities on the acquisition and transfer of strategic skills. Subjects were asked to complete a battery of cognitive tests prior to completing the visual discrimination trials, and a discriminant analysis on factor scores was used to place subjects into groups of high, medium, and low cognitive ability. One of the tests loading most heavily on the factor that accounted for most of the variability in the data was Alderton's Integrating Details test (Alderton, 1989). Subjects were then asked to complete an experiment designed to replicate the first experiment described in this report, but with random polygons rather than airframe silhouettes. . That is, half of the high, medium, and low ability subjects were initially trained to make discriminations between very dissimilar (easy discriminations) polygons, and the other half were trained to make discriminations between very similar (difficult discriminations) polygons.

The results suggest that cognitive ability has a profound impact on the acquisition and transfer of strategic skills. The high cognitive ability group results showed fast and accurate discriminations in Sessions 1, 2, and 3 regardless of initial training difficulty. In contrast, the low ability subjects showed fast and inaccurate discriminations in Sessions 1, 2 and 3 regardless of initial training difficulty. Most important for the Navy, the medium level ability subjects (the largest portion of the population) showed the greatest sensitivity to initial training context. Subjects with medium levels of cognitive ability who were initially trained on easy discriminations showed negative transfer in Sessions 2 and 3. In contrast, medium-level ability subjects who were initially trained on difficult discriminations showed positive transfer in Session 2 and 3.

The implications of this finding include 1) the importance of screening for cognitive ability and in particular for spatial abilities, including Alderton's Integrating Details test, when recruiting sailors with high strategic processing ability, and 2) the importance of designing training to facilitate the development of strategic skills that are optimal for the end task.

CONCLUSIONS: We have completed multiple experiments that suggest a central role for spatial ability, and, in particular, Alderton's Integrating Details test in the ability to acquire and transfer optimal strategic processing skills. We have shown that strategic skills are central to visual discrimination performance and have documented the results in manuscripts. In addition, we have prepared the materials necessary to run experiments to examine the role of strategic processes in Alderton's Integrating Details task in long-term memory for visual stimuli. Due to funding cuts in Manpower and Personnel, year three funding was not obtained, and its accomplishments did not take place. However, the research funded under this grant is providing the foundation for research on Optimizing Strategic Visual Processing. This is funded by a grant recently obtained from the Office of Naval Research, N00014-03-1-0088.

SIGNIFICANCE: In the 21st Century, fewer Navy recruits than in the past will be asked to perform tasks in more complex and dynamically changing environments than ever before in order to meet operational requirements. Many current and future Navy jobs demand that sailors be able to perceive, transform, and comprehend complex spatial information presented in visual displays. For example, aviation, submarine, and surface sonar operators must perceive, transform, and comprehend sound wave patterns in order to classify a contact. These abilities are required by many other Navy jobs, including radar operators who compare visual patterns to identify radar contacts, machinery repair technicians who make visual comparisons between machine parts, and navigators who integrate details of images depicted on tools such as maps to perform locating tasks. Thus, spatial processing abilities enable sailor performance in a broad range of Navy jobs, and strategic spatial processing would optimize sailor performance in these jobs.

IMPACT/APPLICATIONS: Strategic Spatial Comparisons and Information Reduction Theory. Think of two recruits classified into the occupation of sensor station operator. "Jonsey" and "Beaumont" are each asked to learn how to discriminate between the sound wave pattern emanating from a biological (e.g., whale) and a man-made object (e.g., submarine). Jonsey out-performs Beaumont at every turn because Beaumont attends to irrelevant features of sound wave patterns and his comparisons are not sufficiently detailed. As a result, his performance worsens as the noise in sound wave patterns and the similarity between patterns increase. In contrast, Jonsey quickly learns to attend to features of sound wave patterns that are relevant for comparison and he learns to make fine-grained comparisons required for accurate comparisons. As a result, his performance is not impacted as the noise in sound wave patterns increases and his accuracy is high when sound wave patterns are very similar.

What this example suggests is that spatial comparison abilities can be partially characterized as the ability to learn processing strategies that (1) differentiate between relevant and irrelevant information and (2) are sufficiently detailed to accommodate the most difficult comparisons. In general, good performers are likely to know which task information is relevant and which is irrelevant and are therefore able to focus their processing on task-relevant information. In contrast, poor performers do not have the ability to distinguish between task-relevant and task-irrelevant information. One aspect of acquiring a spatial comparison skill, then, appears to be the ability to limit task processing to task-relevant information, an ability referred to as information reduction (e.g., Haider & Frensch, 1999; Doane et al., 1999).

Information reduction ability is acknowledged in many areas of psychology. The phenomenon has been discussed theoretically for the domains of visual perception (e.g., Gibson, 1963), sports and perceptual motor skills (e.g., Abernathy, 1993), educational psychology (e.g., Bransford, Sherwood, Vye, & Rieser, 1986), and expertise (e.g., Ericsson & Lehmann, 1996). For example, Shapiro and Raymond (1989) observed improved performance when novices learned to attend to task-relevant information and to ignore task-irrelevant information. They found that good performers had the ability to acquire an internal comparison strategy that helped to distinguish between task-relevant and task-redundant information and to base task processing on the relevant aspects of a task. Thus, an important question is what cognitive abilities support the learning and performance of strategic comparison processing skills that selectively use relevant information. Information reduction theory suggests that the strategies acquired during training should differ as a function of task difficulty, but it does not make predictions about the transfer of strategies to novel stimuli and their malleability. This is important to explore. For example, if strategies are not malleable, then human information processing would be optimal for only those stimuli viewed during initial training. If they are malleable, then it is important to determine the circumstances and cognitive abilities that encourage the speedy modification of strategic spatial comparisons at transfer to enable optimal processing of novel stimuli.

This work has both theoretical and practical implications. Theoretically, this work will enhance an information reduction theory of learning and will provide important insight into individual differences in human spatial ability. There are practical implications for many areas of human performance, such as optimizing classification tools used to assign recruits into jobs that require the ability to acquire flexible spatial comparison strategies. For example, findings from these studies might extend to optimizing classification for military personnel that discriminate between visual radar contacts.

PATENT INFORMATION: No patents reported.

AWARD INFORMATION: Promoted to Professor, Department of Psychology, Mississippi State University.

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